Solution of Maxwell's Equations Using the Time Domain Method of Moments
Final Technical Report

by

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New algorithms for the time domain analysis of electromagnetic waves in shielded structures are presented. Electromagnetic fields inside a structure under investigation are expanded into series of basis functions and the expansion coefficients are found by means of the Method of Moments. Numerical cost of algorithms and their stability is discussed and cost efficient hybrid approach combining the new technique with a classical FDTD algorithms is proposed. Numerical tests are showing that significant speed up can be obtained for structures with homogeneous regions. A very fast, low return loss absorbing boundary condition (ABC) is proposed which accounts for the highly dispersive character of the structure. A very good performance of the ABC is demonstrated.

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Abstract

New algorithms for the time domain analysis of electromagnetic waves in shielded structures are presented. Electromagnetic fields inside a structure under investigation are expanded into series of basis functions and the expansion coefficients are found by means of the Method of Moments. Numerical cost of algorithms and their stability is discussed and cost efficient hybrid approach combining the new technique with a classical FDTD algorithms is proposed. Numerical tests are showing that significant speed up can be obtained for structures with homogeneous regions. A very fast, low return loss absorbing boundary condition (ABC) is proposed which accounts for the highly dispersive character of the structure. A very good performance of the ABC is demonstrated.

Keywords: Maxwell's equations, waveguides, resonators, absorbing boundary condition. time domain algorithm

Project Description

The project was concerned with the development of new time domain numerical methods for a rigorous solution of Maxwell equations in shielded structures. The method proposed is based on classical method of moments but in the time domain. The objective was to develop computer programs which will allow the assessment of the advantages and drawbacks of a new formulation and comparison with classical time domain algorithms such as FDTD (Finite Difference Time Domain) or TLM (Transmission Line Matrix). The research covered the following scope

1. Assessment of time domain algorithms from the point of view of the alternative representation of fields in order to find formulations which may broaden the range of options available for the time domain analysis of complex problems of electromagnetics.
2. Development of a new computer codes based on the time domain method of moments (TD-MoM) and investigation of numerical (stability, convergence) , properties of the methods
3. Development of the new absorbing boundary condition compatible with the (TD-MoM)
4. Development of an independent FD-TD computer code which was used for benchmarking of a TD-MoM program
5. Comparison of the efficiency of the TD-MoM code with a FD-TD code (for a few test cases)
6. Identification of the class of engineering problems for which new formulation may prove more efficient than FD-TD or TLM

Main Results

The details of the research are contained in the internal report [1]. Here only the most significant accomplishment are characterized. The main results of the project are:

1. Four new time domain algorithms. When applied to practical structures the algorithms performed **from 1.55 to 26 times faster** than a classical FDTD program with a simultaneous **reduction of number of unknowns**
2. Derivation of the stability condition. The stability condition shows that it is possible to operate some of the new algorithms with a time step **greater** than a classical FDTD.
3. A new absorbing condition for new algorithms which is suitable for highly dispersive guides. Not only were **very low return loss (from -80 to -140 dB over almost a decade)!** obtained, but it is implemented in just a few floating operations despite large dispersion. Compared with the results reported in the literature for identical configuration the new ABC ensures **a few orders of magnitude decrease in memory and computer time**.
4. two conference papers, 1 journal paper were published and 2 other journal papers are under review. (1 in print!

Below is a brief description of the main accomplishments of the project

1. New algorithms

1. **Total eigenfunction expansion (TEE): the algorithm employs entire domain expansion functions of three spatial coordinates and the finite difference representation in time. Its application is limited to resonant cavities loaded with inhomogeneous dielectrics. If the inhomogeneity is not large the algorithms is fast, uses fewer number of unknowns and allows much greater time step than FDTD**

2. **Partial eigenfunction expansion (PEE):** the algorithm employs entire domain expansion functions of one or two spatial coordinates and the finite difference representations in time and two or one spatial coordinate. It can be applied to the analysis of resonant cavities loaded with inhomogeneous dielectrics or scattering in waveguides. If the inhomogeneity is not large the algorithms is fast uses fewer number of unknowns and allows greater time step than FDTD. In one numerical test of it performed 26 times faster than FDTD.

3. **Hybrid vector and hybrid scalar partial eigenfunction expansion-FDTD (PEE-FDTD):** the algorithms combine the PEE with the classical FDTD. They can be applied to the analysis of resonant cavities loaded with inhomogeneous dielectrics or scattering in waveguides, analysis of shielded transmission lines and are very efficient if the structure can comprises homogeneous regions bounded in 1 or 2D by PEC or PMC. In those regions vector or scalar version of PEE is used. FDTD is applied in the remaining part allowing fine discretization in critical parts. An iteration step of scalar PEE algorithm is realized using only 2 variables and 5 floating point operations per subregion which is much larger than the FDTD cell which makes it at least **three times more efficient in terms of memory and from 4 to 6 times faster** then any published time domain scheme. The numerical tests for hybrid vector PEE-FDTD showed speed up factor relative to FDTD ranging from 1.55 to 2.9.

2. The stability condition of the algorithms.

The stability condition was derived by investigating the properties of operators in suitably defined Hilbert spaces. Compared to the classical von Neumann stability analysis, the functional analysis approach gives more general results which can be easily applied to some recent and possible future time domain schemes.

3. The absorbing boundary condition

The absorbing boundary condition was developed for the highly dispersive structures. It was designed for PEE algorithm and its derivatives. The unbounded region is modelled as a transmission line. The termination is represented as a cascade of two filters. The first filter is a delay line which is a perfect ABC for a dispersionless guide and the second filter emulates the distortion caused by dispersion. On off line system identification approach is used to model the dispersive character of the termination. The numerical test showed that the new ABC is stable and gives **very low return loss** (from -140 to -80 dB) in almost entire useful frequency range spanning a decade. It requires only **from 2 to 10 additional variables** to be stored and the **computational overhead is marginal**. Compared with the ABC used by other researchers for the same class of problem it gives **a few orders of magnitude in numerical cost reduction**.

Practical significance of the results and development perspectives

The new algorithms are limited to shielded structures and will perform best when the geometry comprises 1 or 2D homogeneous subregions bounded by perfect electric or perfect magnetic conductors. Such configurations or often encountered in the analysis of microwave circuits examples being the rectangular guide-coaxial line transformer, E- plane filters, practically all planar guides. FDTD analysis of such structures requires significant computer resources because the algorithm does not distinguish between discontinuities and the homogeneous regions and propagates the field even through simple domains. The optimal and most versatile algorithm to analyze such geometries is the hybrid scalar PEE-FDTD technique. It retains the versatility of FDTD for critical parts of the geometry while offering the speed up and memory requirements reduction combined with an excellent ABC resulting from the time domain method of moment treatment of homogeneous parts. As discussed in the internal report [1] the application of the new algorithms to the analysis of some open configurations is also possible. Future work should concentrate on the optimization of ABC, the implematation of the algorithms for open space problems and the development of numerical codes for complex practical geometries. Finally the method of moments algorithms should be extended to allow a similar fast treatment of inhomogeneous subregions. This would lead to an ultimately fast algorithm for the time domain analysis of most practical microwave structures.

List of publications and reports

[1] M.Mrozowski, "Eigenfunction expansion techniques in time domain", Technical University of Gdansk, (internal report), April 1994.

[2] M.Mrozowski, "Function expansion algorithms for the time domain analysis of shielded structures supporting electromagnetic waves", J. of Numerical Modelling, April 1994.

[3] M. Mrozowski, " Stability of the Time Domain Total Eigenfunction Expansion Algorithm", Proc. 1993 Asia-pacific Microwave Conf., pp.9-21 – 5-24.

[4] M. Mrozowski, "Derivation of Stability Condition for the Time Domain Method of Moments Algorithms Using Functional Analysis Approach", Time Domain Modelling Workshop, Berlin 1993.

[5] M.Mrozowski, "A Hybrid PEE-FDTD Algorithm for Accelerated Time Domain Analysis of Electromagnetic Waves", IEEE Microwave and Guided Wave Letters, (submitted).

[6] M.Mrozowski, "Stability Condition for the Explicit Algorithms of the Time Domain Analysis of Maxwell's equations", IEEE Microwave and Guided Wave Letters (~~submitted~~)(in print)

List of scientific personnel

1. Michal Mrozowski, PhD - principal investigator